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State of the Art of the Use of Strain Gauges in Roads

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Abstract. This study explores the state of knowledge and state of practices regarding the use of strain gauges in road applications. It outlines the many types of strain gauges that have been used, there properties and how they are installed, pavement design evaluation for pavement with embedded sensors, the types of application in which strain gauges have been used and laboratory and field performance of different strain gauges embedded into the pavement.

Typically, pavement construction with strain gauges are designed using same procedures as traditional pavement. The only common addition is how to introduce strain gauges to the pavement.

A great deal of research has been conducted on the use of sensors in roads. Much of this research has focused on the laboratory and field benefit of using sensor in evaluating pavement performance. The results of this research have been mixed, especially regarding the use of sensors.

The information reported here shows a number of gaps in the state of knowledge. It was found that the information to address the gaps was lacking or inconsistent. Although, the use of strain gauges to monitor road conditions in some application is quite well established and clearly successful to provide better understanding. Research is required to determine or clarify the following:

- Cost effectiveness of using strain gauges
- There is not guidance on construction
- Standard method of collecting and interpreting strain gauges data
- Long term performance

Overall, the reported success of strain gauges is quite promising. There use in some application in concrete structure is well established. Opportunity exist to increase the use of strain gauges in other applications, provided their benefit can be clearly and consistently demonstrated. point font.

INTRODUCTION

We have smart phones, cars and even smart cities, but our roads are still just roads. This project will focus on the state-of-the-art of the future road and will introduce the possibility of constructing smart and multi-functional pavement system embedded with technology, wireless connecting and novel materials to transform ordinary road to smart and multi-functional road.

Climate change and sustainability is a big concern for the integrity of road structure and traffic safety. The continues increases in the number of vehicles has led to an increase in road noise and exhaust gases causing problem to urban residents. This increases in traffic volume and tyre pressure has led to new and different distress types. Therefore, a huge amount of money spends each year on monitoring roads condition and planning their maintenance.

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Smart and multi-functional pavement with embedded sensors should be able to provide data from road enabling optimisation of road structure condition.

Technology is a powerful tool in pavement management system. This technology can be used to provide precise information about traffic, class of vehicles, speed and possibly network pavement conditions. Therefore, embedding sensors within the pavement structure to monitor strain, stress and temperature can lead to reduce maintenance costs and increase pavement service life **D Priyanka et al.** Moreover, embedded sensors may help to improve pavement design procedure by providing more accurate information regarding pavement response under real traffic and climate conditions. It is well known that bituminous materials are viscoelastic materials and their behaviour highly influenced by temperature. It is, therefore, essential to consider climate condition in pavement design process J Read et al and C. Van Grup.

Typical pavement structure consists of four layers surface layer, binder and/or base layer both called bond layers, subbase and subgrade known as unbound layers. In general, bound layers have higher stiffness whereas the unbound layers have a greater thickness with a lower stiffness W Jenks et al. For the pavement to continue perform efficiently the stresses and strains developed at those layers should be within the permissible limits of the material selected. Therefore, the aim of pavement design is to produce a structure that able to distribute traffic loads efficiently at different loading and environmental conditions without causing damage. Pavement design technic and principles is built on theories and procedures. These technic and principles were based on knowledge and previous research achievement that have helped professional pavement engineers to create specific analysis and design methods. As a result, these technics have created a big influence on current pavement technology L Sun.

Various computer programs have been used to estimate the strains, stresses and vertical deflections which occur in the pavement structure as a result of the applied load S F Brown. For instance, Mechanistic-empirical pavement design and analysis (MEPDG) have recently become a wide common practice for pavement design across the United States. This software can determine theoretical load-induced stresses and strains in the road structures based on the pavement structure’s material properties. These stresses and strains are then coupled with Miner’s Hypothesis and transfer functions to estimate service life of the road. It is important to note that theoretical strains and pressures are used in transfer functions to predict pavement design service life. Therefore, accurate pavement responses may help the transfer functions to provide more adequate and reliable pavement design thickness J R Willis and D H Timm.

The aim will be examining different strain gauge types and the possibility of identifying the type that can provide accurate measurement. Getting an actual measurement will help to more accurate prediction of pavement life, improve design procedure and hopefully filed measurements can lead to improve and develop theoretical models.

BACKGROUND

The use of sensors to monitor road dates back many decades. Weigh-in-motion (WIM) systems were firstly introduced for monitoring truck weight in the United States in the early of 1950s. Bending plate WIM systems are considered first sensors used S A Mumayiz and R M Michaels. Strain gauges attached to the underside of the bending plate. Once the vehicle passed over the bending plate, strain gauges measure the bending force applied. New generation of WIM systems was developed in the 80 G G Otto et al. The new systems use piezo-electric technology to measure the wheel load of the passing vehicle. Once vehicle passes over the piezo-electric cable, an electric charge on the conductive surface of the compressed cable was generated D J Clark. Since, then many sensor types and technic have been introduced and used in different applications G G Otto et al. Previous study for the first time examined the possibility of using piezoelectric sensors for measuring axle loads instead of bending plate. It is interesting to note that piezoelectric can convert mechanical energy to electrical energy and the other way around D J Clark.

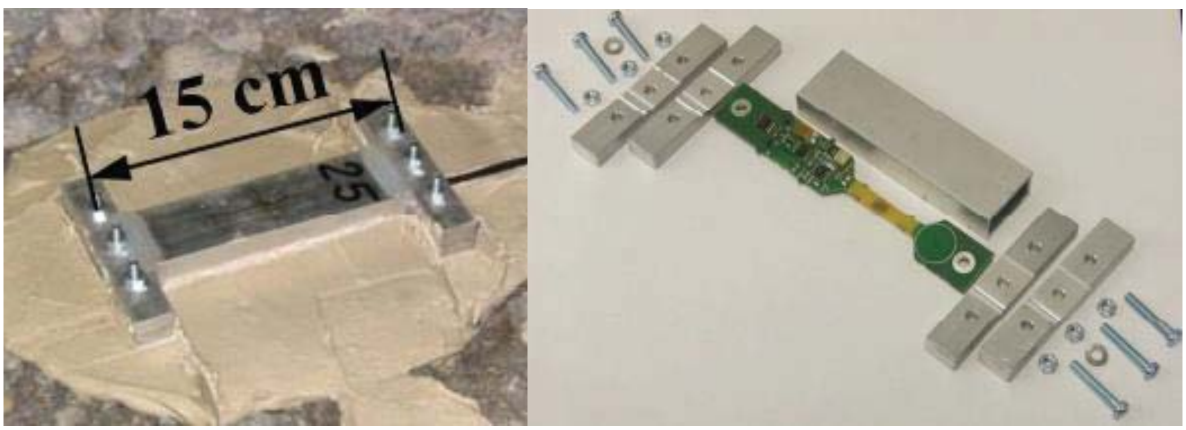
Many researchers started using different types of strain gauges to measure the strain in asphalt pavement layers. The most common types at that time was H-gauges, strain coils and foil strain gauges. The earliest type of H-gauge designed in England by the Transport Research Laboratory (TRL). It was made from aluminum strip with the dimensions of 12.6mm width and 0.25mm thickness. This gauge has 225-ohm resistive foil strain gauge with 101mm length. It is basically two steel bars connected to aluminum strip at 90° angle forming the letter H shape. This gauge was waterproofed N Tabatabaee and P Sebaaly.

STRAIN GAUGE TYPES

BASt Asphalt Strain Gauges

A full-scale pavement test truck study developed strain gauges following the basic design principle. BASt has a strip made of fibre reinforced epoxy-resin used to link the strain gauge on both sides (quarter bridge circuit used in both side). Aluminum case and anchors are used to protect the strain gauge against impact load and high temperature during construction and compaction of the pavement as shown in FIGURE 1. Aluminum anchors transfer the tension and compression forces from the surrounding material to the carrier strip where the strain gauge pattern measures the tensile and compressive strains. There is no shear stress/strain developed from the surrounding material to the strip because the epoxy-resin strip has zero contact with the asphalt. This feature gives advantage to BASt strain gauges over other strain gauges such as (Dynatest and Construction Technologies Laboratories (CTL)). BASt strain gauges dimensions are (150 x 75 x 15mm), length, width and height. These strain gauges are suitable for short term study only. Further modification is required to make BASt strain gauges suitable for long term performance R Rabe. The second generation of BASt strain gauges has the following modification:

- The strip for the new strain gauges used as board for the electronic circuits, processing and memory unit. Temperature accusation become possible as four strain gauges installed into a full bridge circuit.
- A bigger circuit was integrated to provide a better signal quality for the data to be captured.
- Peak detection and classification for data reduction become possible with the new gauges as a microprocessor-memory unit was integrated.
- BASt second generation sensor has the ability to withstand 1,000,000 load cycles.



(a)1st Generation (b) 2nd Generation

FIGURE 1. BASt asphalt strain gauges **R Rabe**

Construction Technology Laboratories (CTL) Strain Gauges

Another type of H-gauge uses strip of chosen material to connect strain gauges on both sides. The shape of letter H basically formed from connecting the end of the strip to a metal bar with a rectangular cross section that act as anchors as shown in FIGURE 2. Applying a load to the pavement produces strain leading the anchor bars to move produce elongation in the strip. Strain gauge starts to measure the deformation as a result of the strip movement. It is believed that the resulting strain in the strain gauge will be similar to the real strain in the pavement if the strip stiffness is match asphalt pavement stiffness. Strip with higher stiffness than the pavement may act as a reinforcement to the pavement. Stiffness difference between strip and pavement should be as minimum as possible because large difference lead to debonding between the anchor bars and the pavement causing instrument failure. Different materials and strip dimensions have been used to overcome this problem N Tabatabaee and P Sebaaly. In general, these gauges have a calibration factor. The calibration process for these gauges should be done twice and the difference in calibration factors should be within ±5% J.R. Willis and H.D. Timm

FIGURE 2. CTL asphalt strain gauges

Dynatest Strain Gauges

Dynatest strain gauges are quite similar to the CTL strain gauges as shown in FIGURE 3. The main differences between Dynatest and CTL are shown in

TABLE **1**. Dynatest strain gauge almost doubles the cost of CTL gauge. These gauges are designed to match asphalt pavement stiffness. Therefore, a good care should be taken in handling and installing them T L Weinmann.

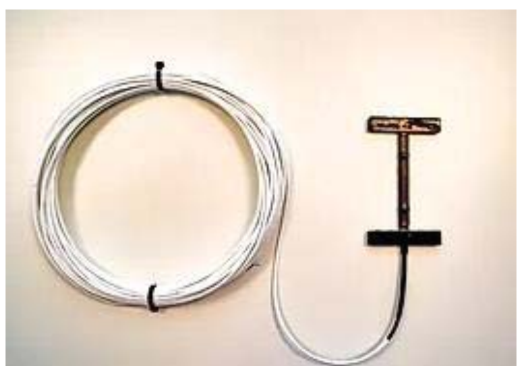


FIGURE 3**.** Dynatest strain gauge

TABLE 1. Comparison between Dynatest and CTL strain gauges T L Weinmann et. al

Specification	**CTL**	**Dynatest**
Temperature range	30-200℃	30-150℃
Circuit type	Full Bridge	Quarter Bridge
Sensitivity	0.11 N/με	0.11 N/με
Cost	500$	670$

Fibre BRAGG Grating (FBG) Sensors

Fibre optic sensor is the type of sensor that cannot be used in the pavement unless a suitable protection provided, otherwise it will break. These strain gauges able to measure both strain and temperature. Previous study used organic modulated, ceramic-coated Draw Tower Gratings (DTG), embedded in a glass fibre reinforced plastic (GFRP) round profile with an outer diameter of 1 mm to protect the sensors as shown in FIGURE 4. The protection material used can measure high strain level (>10000 μm/m) and expected to show a good long-term stability under the effect of repetitive loading. These sensors after the protection showed high strength and operational temperature up to 200°C P. Kara. Table 2 shows the mechanical properties of FBG sensors. It is widely used for research purpose.

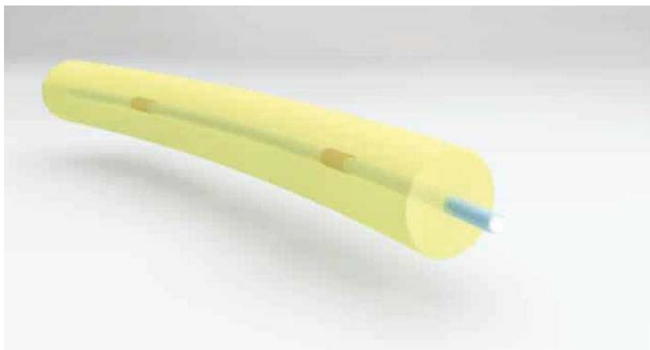


FIGURE 4. Fibre Bragg Grating sensors with DTG protection FBGS

TABLE 2. Mechanical properties of FBG sensors FBGS

Specification	Value
Temperature range	-40 - 120℃
Elastic Modulus	≥ 48 GPa
Maximum Tensile Strain	25000 με
Maximum Longitudinal Load	950 N
Minimum Bend Radius After Installation	100mm

Piezoelectric Sensors

This type of sensor uses piezoelectric material to convert measured strain or force to an electrical signal. This sensor able to work at very high temperature up to 1000°C if it is manufactured from specific materials such as (gallium phosphate or tourmaline) D NAM. The possibility of manufacturing self-powered piezoelectric sensors makes this type of sensor preferable of most up to date research. The electrical energy generated in this sensor under the effect of the load is used to supply calculation circuit with energy. Calculation circuit is where the data and strain information stored. However, the commercial type of these sensors (piezoelectric ceramics), is brittle with high modulus compared to flexible pavement. Therefore, the embedded sensors in the asphalt is high likely to be damaged under the effect of the load. Previous studies developed different piezoelectric sensor design that capable of measuring the damage in the asphalt pavement.

CONCLUSION

This project focused on the state-of-the-art of the future road and introduced the possibility of constructing smart and multi-functional pavement system embedded with technology, wireless connecting and novel materials to transform ordinary road to smart and multi-functional road.

Getting an actual measurement will help to more accurate prediction of pavement life, improve design procedure and hopefully filed measurements can lead to improve and develop theoretical models. Therefore, in this work, different strain gauge types have been examined and the possibility of identifying the type that can provide accurate measurement. It can be concluded that:-

- There is no shear stress/strain developed from the surrounding material to the strip of BASt strain gauges because the epoxy-resin strip has zero contact with the asphalt. Although this feature gives advantage to BASt strain gauges over other strain gauges such as Dynatest and CTL, but BASt strain gauges are not suitable for long term study in comparison with others even after modification.
- In Dynatest and CTL strain gauges, stiffness difference between strip and pavement should be as minimum as possible because large difference lead to debonding between the anchor bars and the pavement causing instrument failure. Different materials and strip dimensions have been used to overcome this problem, but still this is a disadvantage for these two types of gauges. More research maybe needed it.
- The FBG strain gauges able to measure both strain and temperature. They are protected inside a glass fibre reinforced plastic (GFRP). The protection material used can measure high strain level (>10000 μm/m) and expected to show a good long-term stability under the effect of repetitive loading. These sensors after the protection showed high strength and operational temperature up to 200°C. These are advantages for this type over the previous three types.
- The piezoelectric sensors use piezoelectric material to convert measured strain or force to an electrical signal. This sensor able to work at very high temperature up to 1000°C if it is manufactured from specific materials such as (gallium phosphate or tourmaline) D NAM. The possibility of manufacturing self-powered piezoelectric sensors makes this type of sensor preferable of most up to date research. Further studies are recommended.

The information reported here shows a number of gaps in the state of knowledge. It was found that the information to address the gaps was lacking or inconsistent. Although, the use of strain gauges to monitor road conditions in some application is quite well established and clearly successful to provide better understanding. Research is required to determine or clarify the following:

- Cost effectiveness of using strain gauges
- Best method to install strain gauges
- No guidance on construction
- Recognised method on collecting and interpreting strain gauges data
- Long term performance

Overall, the reported success of strain gauges is quite promising. There use in some application in concrete structure is well established. Opportunity exist to increase the use of strain gauges in other applications, provided their benefit can be clearly and consistently demonstrated.

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